14 MEI 1979

C O N F I D E N T I A L.

AR 59 - 218
29.08.1978

COMPACT DISC SYSTEM.

I. INTRODUCTION.

There is a constant endeavour to improve the quality and ease of manipulation of audio systems. After the initial 78 - rpm disc, these efforts have led i.a. to a 12 - in. long - playing disc with good quality characteristics. Also in the domain of the player the continuous evolution of e.g. the pick-up head, tonearm and speed control has resulted in outstanding audio equipment.

The limitations of the conventional phono system are however, evident: essential limitation in the signal - to - noise ratio and dynamic range up to approx. 60 dB, the sensitivity to dust and scratches of the disc and the wear of disc and stylus as a result of the mechanical scanning system, together with a limited ease of manipulation due to the large diameter of the disc.

The Compact Disc system means a break-through of these technical barriers thanks to the introduction of:

a. optical readout
b. digital coding by means of Pulse Code Modulation (PCM)

Consequently, the information on the disc becomes - to an important extent - intensitive to dust and scratches. Moreover the optical information system offers the possibility of high density of information, thus leading to an attractively small disc diameter with a playing time of 1 hour.

The PCM-coding system makes the music quality independent of the disc properties and quarantees an SNR better than 85 dB thanks to the 14-bit linear quantization system chosen and the pre-emphasis applied.

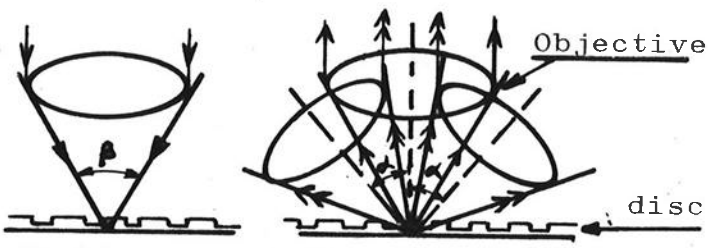
Characteristic of the Compact Disc system is the possibility provided in the coding system for additional information about the music program. In this way it is made possible to play the disc in programmed sequence and to reproduce program information on a display in a more or less extensive way.

A compact design of optical system and player is obtained i.a. through the application of a laser diode as light source and by making the optical system in its entirety follow the track.
The optical system could thus be realised as a small optical pickup unit (OPU).

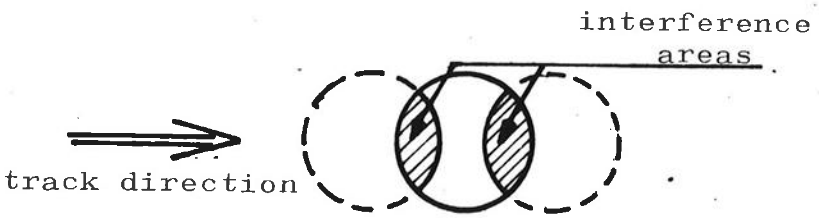
II. OPTICAL READOUT.

The information is stored on the disc in the form of pits along a spiral track. The information is read out by means of a focused light beam that follows the track. Through scattering of light at the pits the intensity of the reflected light is modulated. This goes on as follows:

Part of the light reflected at the track is deflected by diffraction at an angle depending on the pit geometry. The smaller the pit, the greater the angle of deflection. Part of the diffracted light is reflected back into the objective lens (see Fig. 1).



Scattering of the reflected light cone to a periodical structure of pits.



Section of the partially scattered lightbeam

Fig. 1

With a suitable selection of the pit depth, a phase difference of one half of the wavelength exists and, consequently, cancellation of light will occur in the hatched areas.
This reduction in light is measured by a photodiode (see ch. III: Optical system) and results in a modulated electric signal.
According as the pits become smaller, a smaller part of the light beam will be modulated in this way and a corresponding decrease of the modulation depth will be the result. This imposes a limit on the pit size and also on the information

density on the disc surface for a chosen top angle (B) of the readout light beam.

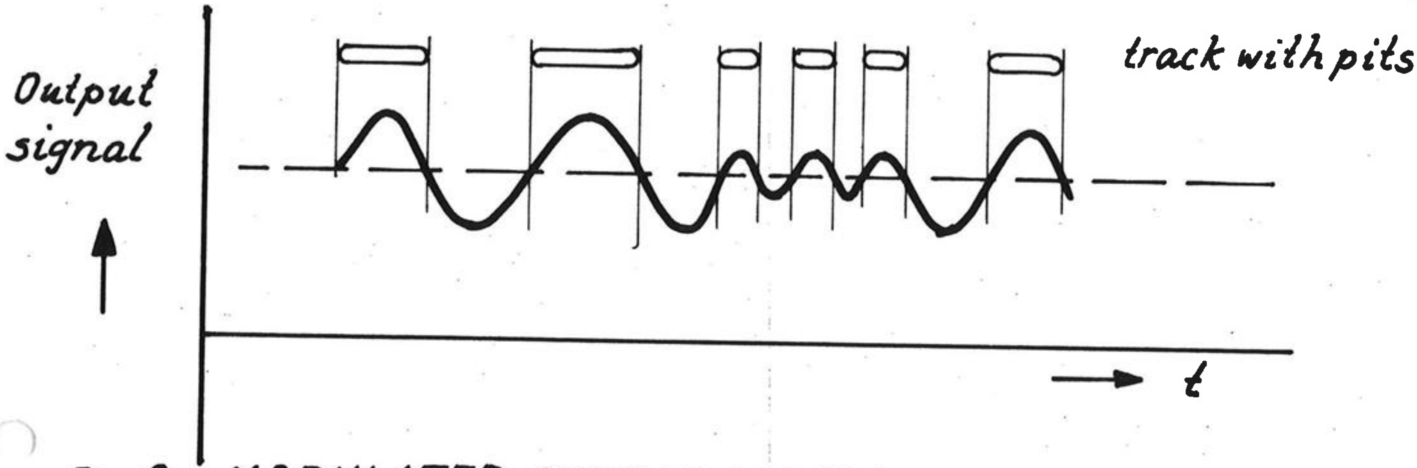


Fig. 2 **MODULATED OUTPUT OF THE DETECTION DIODE**

The upper limit of this top angle is determined by the sensitivity of the readout system to mechanical imperfections of the disc (not perfectly flat and not perpendicular to the axis of the light beam).
As a measure for the light beam top angle the numerical aperture (N.A.) = sin(1/2β)is taken.

III. OPTICAL SYSTEM.

The purpose of the optical system is to convert the pit structure of the track into an electric signal. However, for correct following of the track, control systems will be required in order to keep the read spot centered on the track.
For that purpose the optical pickup unit generates error signals which indicate whether the disc is in focus and whether the read spot is correctly following the track in the radial direction.

The optical pickup unit is shown in Fig. 3. With the help of the first lens, the divergent light emitted by the laser diode is collected into a parallel beam which is directed towards the main objective lens.

Between the first lens and the laser a half mirror is placed that serves as an output-coupling mirror for the reflected light going to the photodiode.

The laserdiode, half mirror and photodiode are mounted in a small tube with a lenght of 40 mm and a diameter of 12 mm.

This entire is mounted in the end of a rotatable arm over which the main objective lens is placed.

The objective lens is mounted over the unit and can follow the disc in focusing direction.

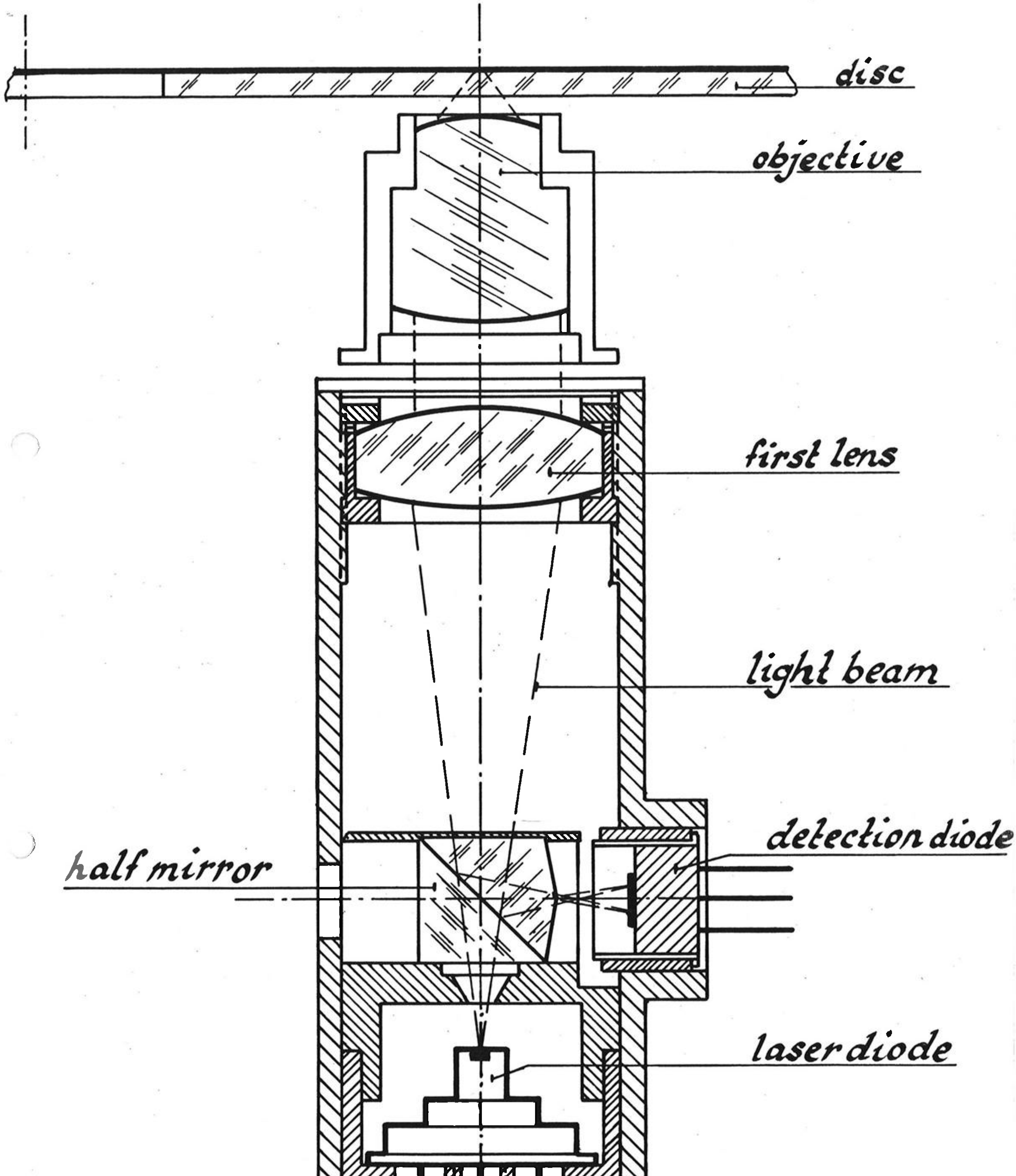


Fig. 3

OPTICAL P.U - UNIT

The complete arm to which the optical unit and main objective lens are attached, is moved in the radial direction by means of a segment motor.

IV. GENERATION OF FOCUS AND RADIAL TRACKING ERROR SIGNALS.

As the light is focused on the disc in the form of a tiny spot, it is essential that the information-carrying plane is always situated with great precision in the narrowest construction of the spot. Since the depth of focus of the spot is small (approx. 2 μm) an active focusing system is required to cope with variations in disc height and with mechanical tolerances. With the help of a tracking system and a drive system on the objective lens it is possible to keep the spot focused on the information. To achieve this, we need a signal indicating whether or not the disc and the spot are in focus with respect to each other.

For this purpose, several methods can be used.
The method applied in the compact disc player can be described as follows:
The photodiode array consists of 3 diodes parts (Fig. 4).
In axial direction the photodiode array is placed in the reimageing point of the spot.
When the disc is perfectly in focus, the reflected light beam is split ut in two parts by passing it through the half mirror and the double-wedge. One half on the beam lands precisely at the separation between two diodes, the other half lands on the third photodiode.
The three photocurrents, summed, constitute the R.F. signal.
The focus signal is obtained by subtracting the photocurrent of diode 1 from that of diode 2. When the disc is in focus, the focus signal will be equal to zero. When the disc is inside focus, i.e. too close with respect to the objective lens, the reimage point of the reflected beam will land behind the photodiode, in other terms photodiode 2 will be exposed, whereas photodiode 1 will receive no light.
The result is a difference signal between the diodes.
When, on the contrary, the disc is outside focus, i.e. too far with respect to the objective lens, photodiode 1 will be exposed and photodiode 2 will not. This will again result in a difference signal, of opposite polarity however.
The focus error signal as a function of the defocusing is given in Fig. 5.
The two spots are also containing information about the radial tracking error; the radial tracking error signal can be derived from the currents delivered by the photodetectors.

V.CODING SYSTEM.

Recording music in digital form on a disc offers great advantages. The most important advantages are:

1. The noise in the transmission channel is not determined by the disc, but by the code chosen. Consequently, it is no longer possible to speak of good and bad discs.

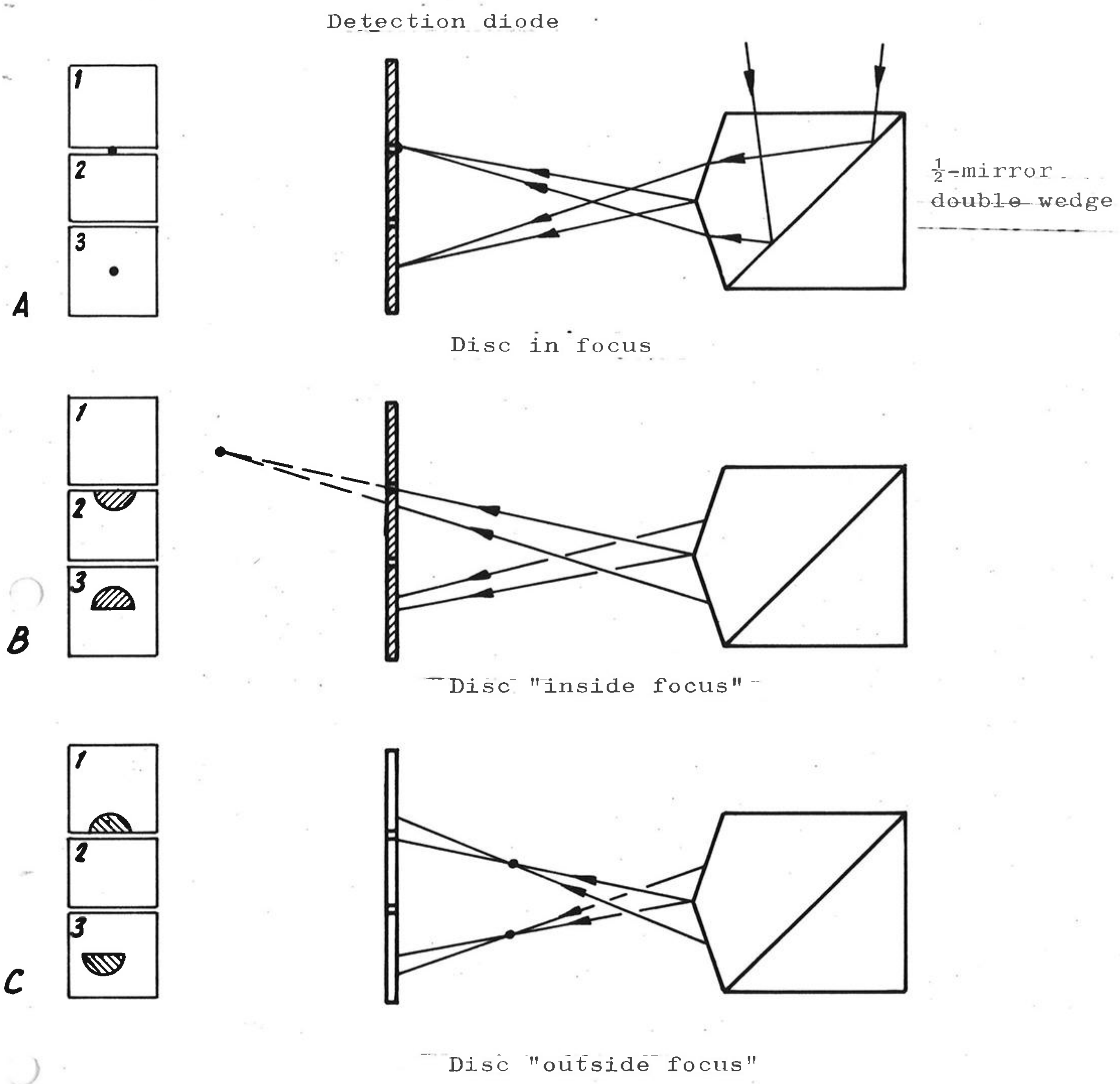


Fig. 4 GENERATION FOCUS ERROR SIGNAL

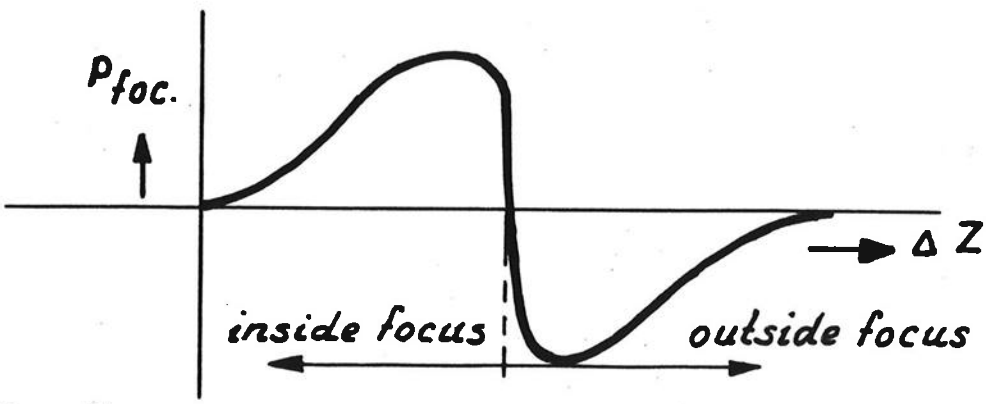


Fig. 5

FOCUS ERROR SIGNAL DUE TO DEFOCUSSING ΔZ

2. The frequency response can be very flat and independent of the disc properties.
3. Disc surface deteriorations, which are clearly audible when present on a conventional long-playing disc, can be made totally inaudible with the help of an error-correcting system.
4. Besides music, other data can be added in encoded form, such as text and program information.

During conversion on the analog signal into the PCM signal, the analog signal is first sampled with a frequency more than two times as large as the bandwidth (20 kHz) of the music signal.
Next these samples are linearly quantized and converted into binary coded words. (Fig. 6).

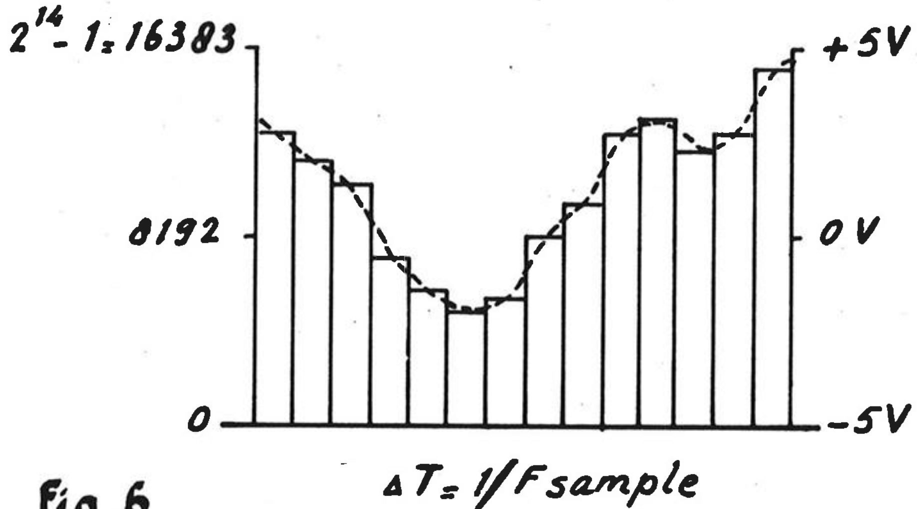


Fig. 6

ANALOG-DIGITAL AND DIGITAL-ANALOG CONVERSION

The number of bits obtained during this conversion is 14, so that-in theory- the SNR will be 85,8 dB. Application of pre-emphasis will result in a further improvement of the SNR up to 92.3 dB.

To the 14-bit words extra bits are added to allow correction of the bit errors. As error-correcting code a burst-correcting code is applied.

Every 12 words a synchronization word is addes for channel-code demodulation and word synchronization. The synchronization word contains two additional bits for adding program data in encoded form. The coding format is shown in Fig. 7 A.

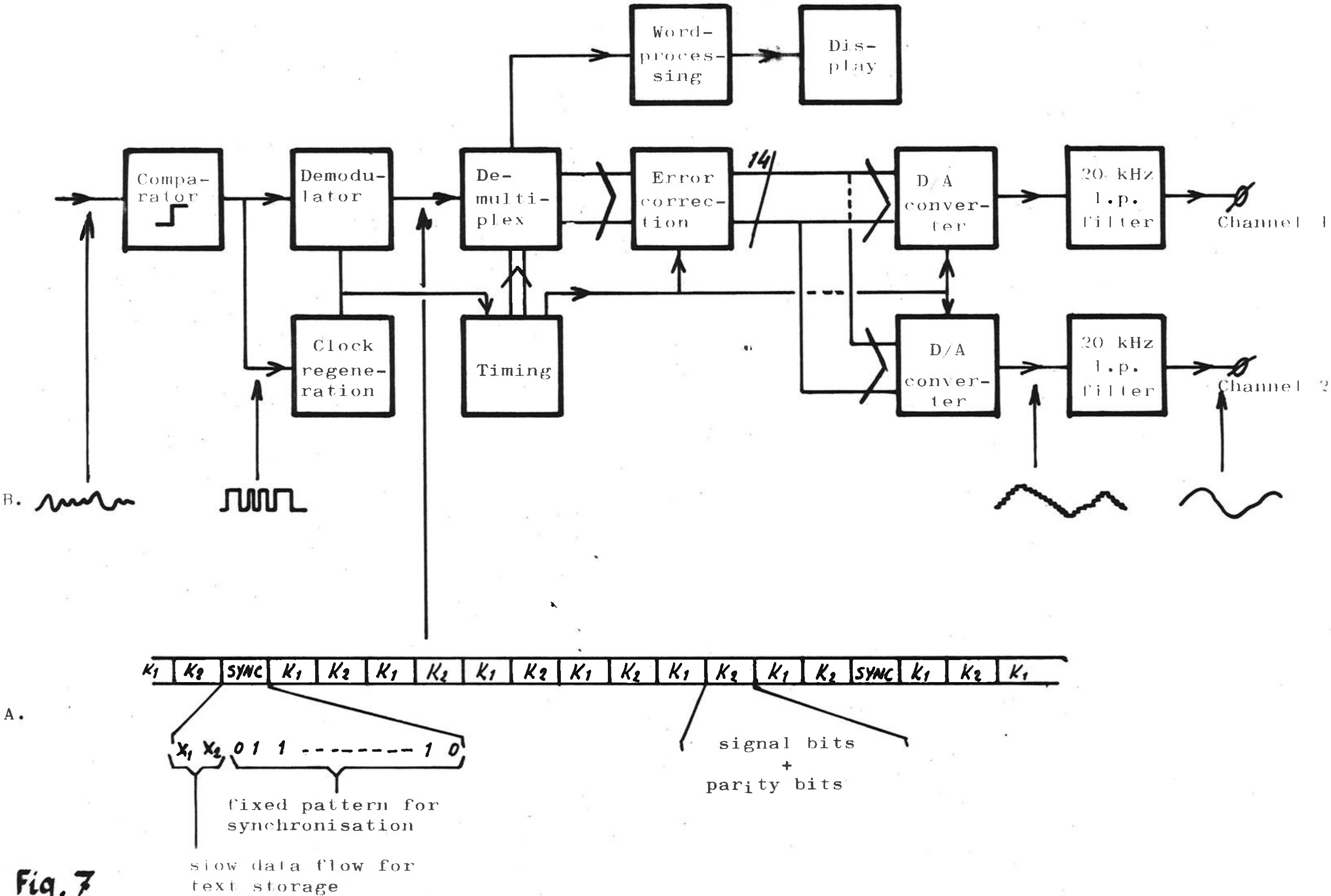

Word-processing
Display
Comparator
Demodulator
Demultiplex
Error correction
14
D/A converter
20 kHz l.p. filter
Channel 1
Clock regeneration
Timing
D/A converter
20 kHz l.p. filter
Channel 2
B.
A.
K_1 K_2 SYNC K_1 K_2 K_1 K_2 K_1 K_2 K_1 K_2 K_1 K_2 K_1 K_2 SYNC K_1 K_2 K_1
X_1 X_2 0 1 1 - - - - - - - - 1 0
fixed pattern for synchronisation
slow data flow for text storage
signal bits + parity bits

Fig. 7

After insertion of the synchronization words, the bit current is adapted for recording on the disc by means of channel coding. During readout of the disc, decoding on broad outline is the reversal of the coding process described.
Finally the original binary words are fed to the D/A converters. These D/A converters are of a unique design, enabling the manufacture of the 14-bit DAC in a monolithic IC by means of the standard IC technology. The block diagram of the decoding procedure is shown in Fig. 7B.

Several data concerning the coding system are summarized in the following table:

Quantization	: 14 bits, linearly coded
Code	: offset, binary
Sampling frequency	: 44,33 kHz
Frequency range	: 20 Hz - 15 kHz ± 0,5 dB 10 Hz - 20 kHz + 0,5 dB - 3 dB
Number of channels	: 2
Pre - emphasis	: 50 µs
Dynamic range	: better than 85 dB
Signal-to-noise ratio	: better than 85 dB (linear measurement)
Harmonic distortion	: less than 0,05% (full modulation 10 Hz - 20 kHz)

VI. SERVOSYSTEMS AND CONTROL LOGIC CIRCUIT.

One of the essential advantages of the COMPACT DISC system is that the optical pickup unit (OPU) has no mechanical contact with the "groove" as a normal phono pickup has. Therefore the radial (arm) and vertical (focus) positions have to be controlled via servosystems which minimize the optically detected deviations from the ideal detecting position.
Due to the sharpness of the detecting light spot, these servosystems have to work with utmost precision and speed.
The same holds for the control of the turntable speed in order to avoid wow and flutter. The block schematical diagram (Fig. 8) of the servosystems therefore contains three control systems for focus, horizontal position and turntable speed, respectively.

Using the random access facility of the C.D. system makes it necessary to move the arm to a predetermined position.
Therefore the arm control system works either with the track error signal (which should be minimized) or with the arm position signal (which should be brought to a predetermined value) as an input quantity, the selection being done by the control logic system.

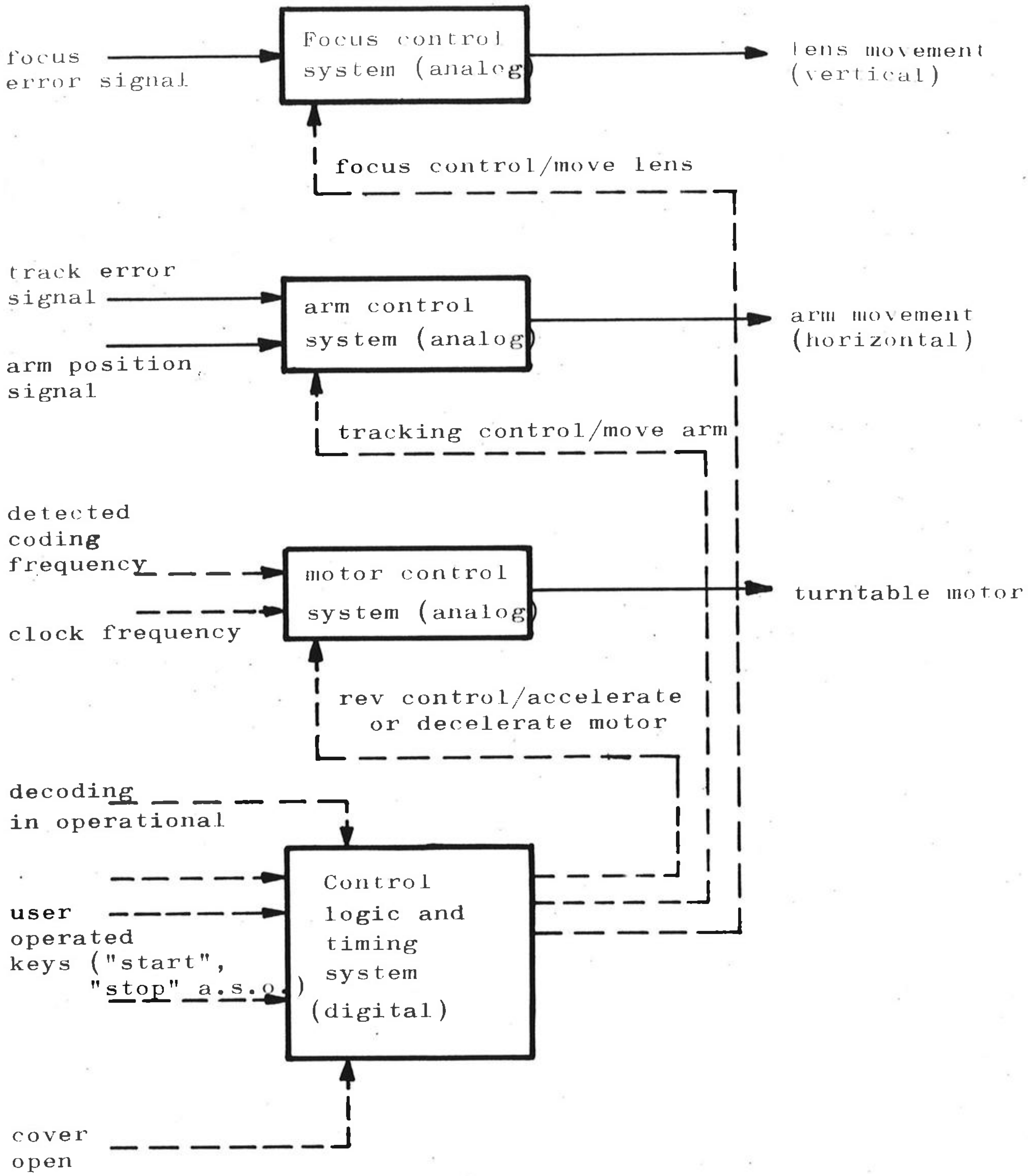


Fig. 8 BLOCK DIAGRAM OF THE SERVO AND CONTROL SYSTEM OF THE COMPACT DISC PLAYER

The turntable speed varies with the detection radius to give a constant linear velocity (CLV). In order to exactly reproduce the speed used during recording the motor control system controls the turntable motor to make the detected digital coding frequency equal to a standardized clock frequency.

Usable signals for focus error and track error are only obtainable if the correct position is already reached to within some μm for the vertical and to within some 0,1 μm for the horizontal position. Therefore to start playing, the control systems have to be disabled and the OPU has to be brought into the working range of the control systems. The motor control also works only within a certain range of speed around the standard frequency, so this circuit must be included in the startup procedure. If for some reason the OPU gets outside the control range of one of the systems (e.g. by a mechanical shock from the outside world) a "decoding inoperational" signal tells the control logic that parts of the procedure have to be repeated.
The control logic system initiates further the correct reaction to user-operated keys("start", "stop", a.s.o.) and cares for the security of user, disc and player by switching off the player when the cover is opened.

VII. MECHANICAL DESIGN OF THE COMPACT DISC PLAYER.

The mechanical design of the compact disc player has to meet the following requirements:

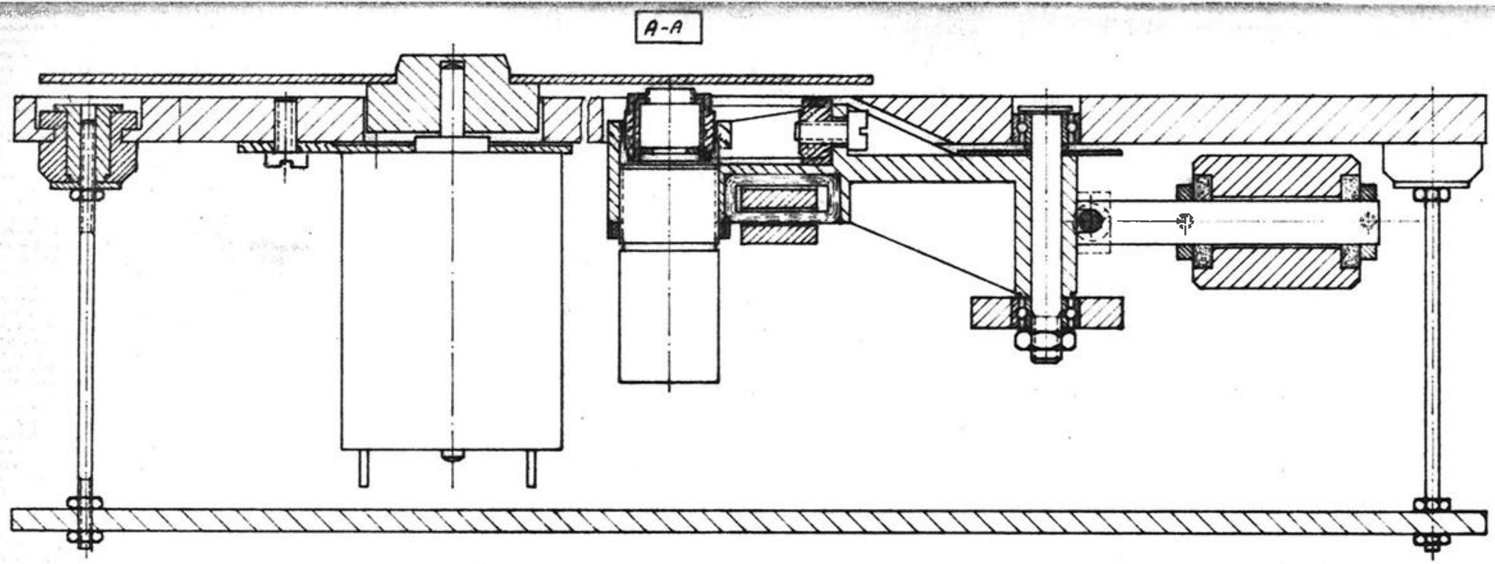
- the OPU (Optical Pickup Unit) must be able to follow the track on the disc in the radial direction, not only in the case of slow displacements, but also in the case of much faster movements due to out-of-roundness and eccentricity of the track;
- the OPU must be able to follow the track in focusing direction (perpendicular to the disc);
- for the search of a definite piece of information on the disc rapid displacement of the OPU is a prerequisite (random access);
- reduced sensitivity to shocks;
- the construction must be compact and low-cost.

Above requirements have resulted in a design in which the OPU is displaced by means of an arm construction with balancing weight, whereas the disc is driven by means of direct drive.
This conception requires a stiff construction without play.
The C.D.player comprises the following units (see Fig. 9):

a. arm + OPU + balancing weight

b. sub-chassis + motor with disc clamping facility

c. location indicator.



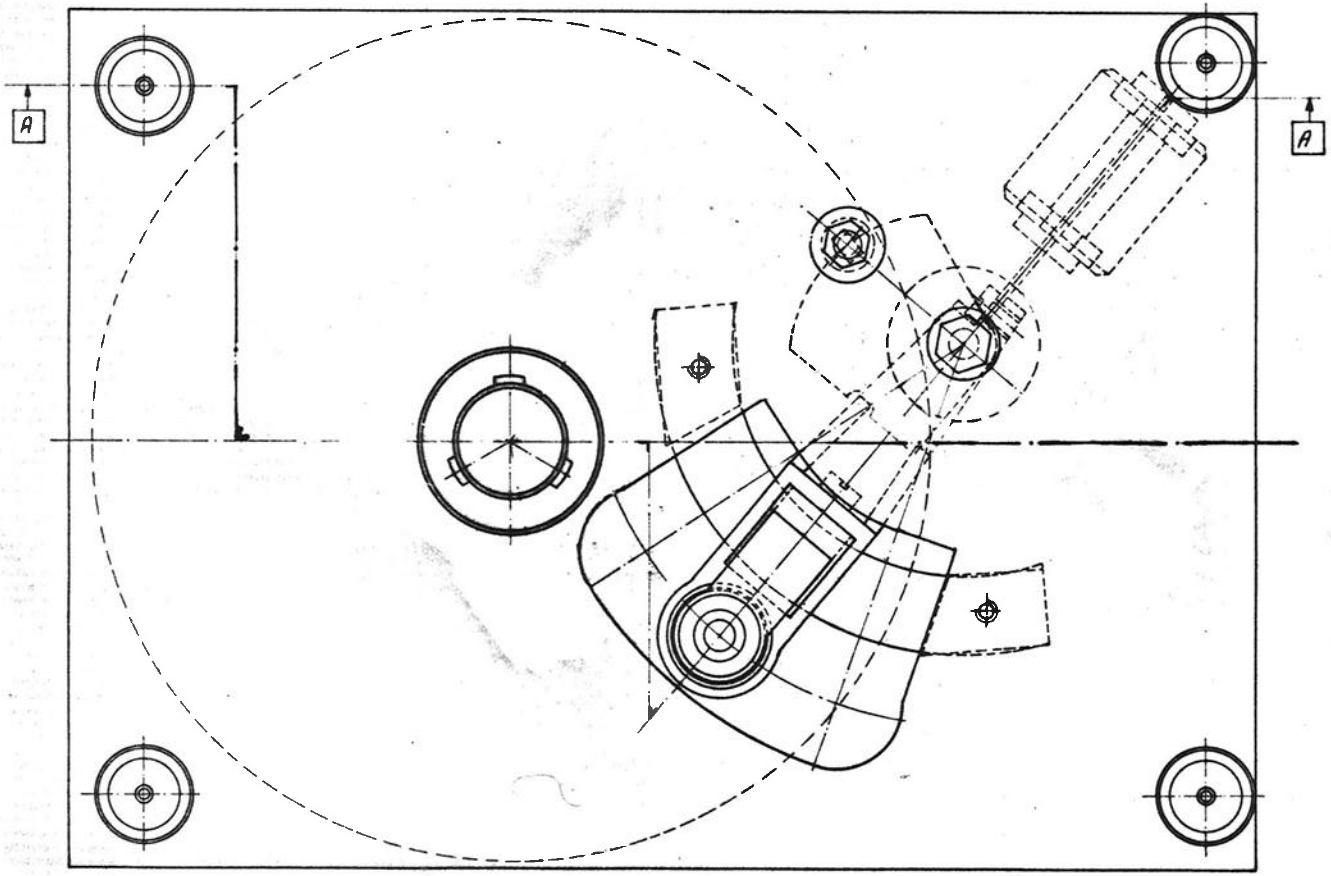


Fig. 9

Mechanical design of the compact disc player

sub a.

The arm is rotating on 2 prestressed ball bearings fixed onto the sub-chassis. In the arm a coil is mounted which forms part of the segment motor. The stator of the segment motor with magnets is rigidly attached to the sub-chassis. The segment motor is used for the radial displacement of the OPU.

The OPU is mounted at the far end of the arm. It comprises a stationary part and a movable objective. The objective lens is driven perpendicularly to the disc by means of a compactly constructed magnet system.
To balance the arm, a balancing weight is mounted onto it.

sub b.

The spinning motor is attached to the sub-chassis. On top of the motor the turntable is mounted. The latter has been designed so that the disc is clamped to the turntable during playback.
The assembly consisting of arm + spinning motor + sub-chassis is damped spring-mounted onto the main chassis.

sub c.

The function of the location indicator is to measure and control the radial location of the OPU. The location indicator consists of a LED and a photodiode, mounted one above the other onto the sub-chassis. Between these two elements a rotating vane is mounted, attached to the arm. This vane partly intercepts the LED beam. The shape of the vane is such that the photodiode current varies linearly with the radial displacement of the OPU.

VIII. DENSITY OF INFORMATION.

The size of the smallest readable pit is determined by the optical system. The highest spatial frequency found on the disc is approx. 640 lines per mm. The maximum amount of information across the entire disc is obtained by reading out the information at a constant lineair speed, irrespective of its place on the disc. The rotational speed must therefore be variable.
The track-to-track spacing is 1,66 μm. Consequently the information density is approc. 0,77 Mbit per sq.mm.

IX. SENSITIVITY TO DUST.

The pits are extremely small, having a width of approx. 0,6 μm and a minimum lenght smaller than 1 μm.

Dust particles in a normal living-room have an average size of approx. 20 µm and would mask an unacceptably large part of the information when lying in the information plane. (Fig. 10).

The same aplies to scratches. Therefore the information is covered with a 1,1 mm thick layer of transparent plastic. Readout is done through this layer. The diameter of the light beam at the place where it enters the disc surface is 1 mm (1000 µm), so that a dust particle will intercept relatively little of the beam (compare this with dust particles on spectacles or on the wind shield of a car).

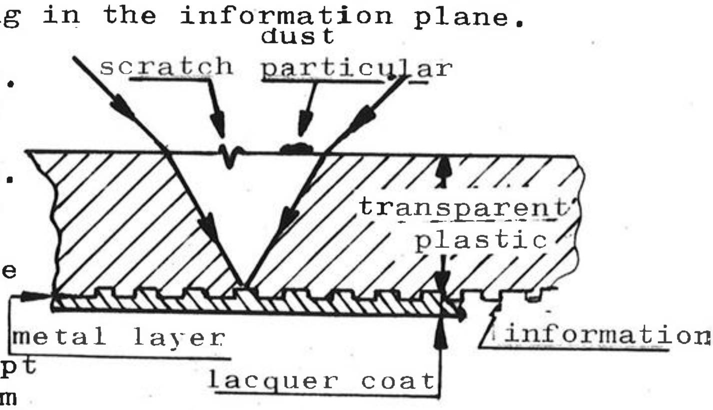


fig. 10

Needless to say that an extremely large amount of dust and wide scratches will certainly affect readout.

X. DISC REPLICATION.

The information is written in photoresist on a so-called master recording machine. The pit pattern obtained after exposure and development is copied into an electroformed metal mother. This mother is multiplied by means of standard disc-reproducing methods. With the stampers thus obtained discs are pressed in transparant material with the help of standard pressing techniques.

A second replication method consists in UV curing of a photoresist layer placed between the master and an approx. 1 mm thick, transparent substrate.

After realisation of the pit relief an extremely thin metal layer (aluminium) is evaporated to make the disc reflective. The metal layer is protected against scratches, dust, etc. by a thin, hard lacquer coat (approx. 10 µm thick).

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